# How far is far enough? Towards an adaptive and "site-centric" modelling integrating co-visibility constraints for optimal land use

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In this article, we propose a renewed site-centric solution that allows us to characterize a specific region of interest by defining the extent of the surroundings that influence sunlight exposure. The proposed method is a mix of an adaptive refinement and a visual-based clipping technique. This method has been implemented in the SketchUp context and applied to three sites located next to the French historical thermal town of Aix-les-Bains.

## I INTRODUCTION

Urban planning policies aim at defining the conditions of human settlements. Coherence and convergence of public action rely on the spatial continuity of its field of application for common issues. That is why French planning regulations tend to follow a concerted process led on several municipalities. They operate through planning regulations which are the expression of a political answer to issues emerging from territorial analyses. These analyses reveal the complexity of the territory by describing the local implications of the relations between cultural, physical and anthropological phenomena. Terrain features, settlement patterns, vegetation and infrastructures do not only influence environmental parameters, such as the amount of solar energy potential and daylight availability, in existing and planned urban fabric, but they also define the way in which inhabitants perceive their environment.

For this reason, urban planning practices should consider at the same time, and alongside urban regulations, perceptual, environmental and climate features in available and potential construction sites. Within this context solar exposure takes on great importance in terms of energy efficiency, quality of public and private spaces, and physical-perceptual enhancement of the local eco-system.

The availability of high resolution terrain and buildings models, the improvement in computation capability, and the development of 2.5D modelling simulation tools, based on image processing computation have provided, in the last decades, essential means for obtaining effective solar analysis from territorial to city scale (Prévot *et al.*, 2011; Morello *et al.*, 2010; Morello & Ratti, 2009; Floriani & Magillo, 2003; Tandy, 1967). However, simulations conducted on large and detailed raster grid models, the format commonly used by public agencies to deliver these basic data, are still costly operations, due to the amount of data needed, and tools based on image processing approaches do not permit yet an effective integration with vector-based solutions used in urban planning practices.

In large and complex topographic areas the influences of the various territorial features, even far from the actual position of the chosen sites, should be carefully considered. That is to say, by considering just the immediate surrounding of a site we can over- or under- estimate the solar contribution in terms of energy and sunlight. But which are the features to consider? Which is the level of detail they should provide? And how can we ensure an accurate simulation model able to provide reliable results in a reasonable amount of time? In other words, *how far is far enough*?

The aim of this explorative research is to propose a site-centric simplification method, based on 3D visibility analysis, in order to obtain a vector-based terrain model easier to handle, faster to compute. The entire process is integrated, as a series of extensions, for a well-known CAAD system, Trimble SketchUp. Three case studies, illustrating different levels of topographic constraints, will be used. Potentialities and limitations of the method will be highlighted in the discussion and further investigation will be proposed.

## II METHOD

### Pre-processing

The spatial datasets are provided by the IGN[1], a national French institute in charge of the management and updating of geodesic and leveling networks, aerial photographs, and geospatial data. More precisely the aforementioned datasets are part of the French Large Scale Reference system (RGE): Digital Elevation Model or DEM (RGE® ALTI 5 m) in raster format for the representation of the landform (supposedly free of vegetation, buildings, etc.), and 3D vector models of significant spatial features such as footprints of individual buildings, forest cover, etc. (BD TOPO® 3D).

The needed pre-processing operations has been made using the Geospatial Data Abstraction Library GDAL/OGR (GDAL, 2016). Specifically the merging of the geospatial data, obtained through "*gdal_merge.py*" command line tool in the context of raster-based tiles or "*ogr2ogr -update -append*" command line tool in the context of vector-based layers; the clipping of data sources to some specified bounding box by using "*gdalwarp*" in the context of raster-based tiles or "*ogr2ogr -clipsrc*" in the context of vector-based layers.

To generate 3D vector contour files from the input raster DEM, the "*gdal_contour.py*" command line has been used and the resulting polylines have been simplified using the "*ogr2ogr -simplify*" tool. The simplified contour polylines are then reused to build the various Terrain Models presented hereafter.

### A two-step process: adaptive refinement and visual-based clipping techniques

The objective, after the conversion of the raster-grid model in a vector-based model, is to refine the virtual model of the terrain with an acceptable trade-off between the amount of data, and thus computation time, and data accuracy. Several terrain configurations have been produced and compared. However, only three of them will be detailed in this presentation.

[1] The *Institut national de l'information géographique et forestière* (National Institute of Geographic and Forestry Information, IGN), is a French public state establishment to produce and maintain geographical information for France.

The “reference” Terrain model (M1) has the same planimetric resolution (5 meters) for the whole region, as provided by the original IGN dataset. In this first model there is no difference between studied parcels and the surrounding landscape, and the entire complexity of the terrain is represented. A side effect of this model is that even the areas that do not influence the chosen sites are precisely modelled. The “mixed” Terrain model (M2), combines the high resolution model of the three selected sites, with the low resolution model of the rest of the whole region. The third model is the “local” Terrain model (M3), where just the selected site and their immediate surroundings are considered. The mixed Terrain model (M2) is therefore some sort of intermediary between two extreme solutions. On the one hand, the "local" Terrain model (M3) does not take into account far distances’ masks. On the other hand, the "reference" Terrain model (M1) is unnecessarily precise all over the wide region.

The three models have been developed using the contour lines obtained during the preprocessing phase, and then imported as SHP file (through a tool developed by one of the authors) in SketchUp. Through the existing tool “*Sandbox From Contours*”, the contour lines have been converted into a Terrain Model (Triangulated Irregular Network or TIN). Lastly, the building footprints have been imported as SHP file, drape on the terrain surface and extruded using the elevation values given as attributes.

The adaptive refinement of the Terrain models consists in the spatial union of two different sets of contours lines layers, with distinct spatial resolutions. Connections between this two datasets are automatically handled by the SketchUp “*Sandbox from Contours*” tool. The three images presented in Fig. 1 show a) the boundaries of the immediate surroundings of the studied site (the red polygon was obtained as a 300 m radius buffer) b) the spatial union of the two contours lines datasets, with different resolutions, and c) a 3D sketch of the result in SketchUp.

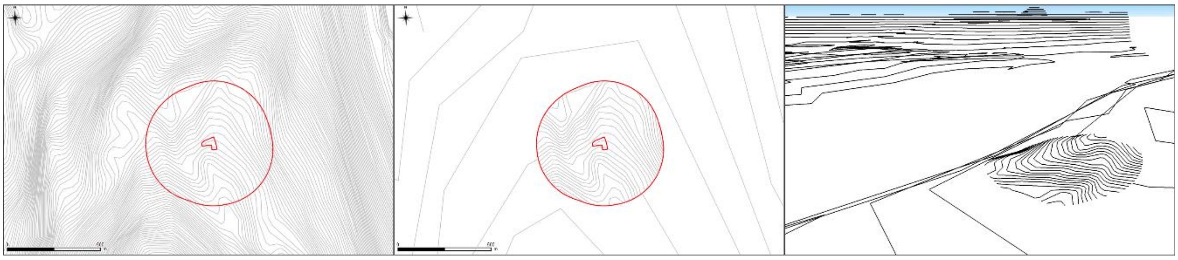

Figure 1: The refinement technique used to adapt the resolution of the Terrain model. The contour lines outside the red polygon of the studied site, have been replaced by lower resolution contour lines.

In order to further reduce the amount of data to be processed, a visibility-based clipping technique is used, considering that the hidden parts of landscape, from a given position, will not influence the studied area in terms of solar exposure.

A 3-step method has been implemented in SketchUp. First of all, we placed, over the three selected areas, a point grid with a fixed step equal to the resolution of the terrain obtained by IGN. For each of the sampling nodes, a 3D viewshed is computed using our extension based on the native ray casting engine of SketchUp. Finally, the spatial union of all these viewsheds is assessed and, to avoid any interpolation effect in all concavities during the TIN building phase, the convex hull of the resulting spatial union is delineated (see Fig. 2). The convex hull is then reused to clip the coarse-grained contour lines, and therefore (potentially) divide by two the area of the region to be taken into account.

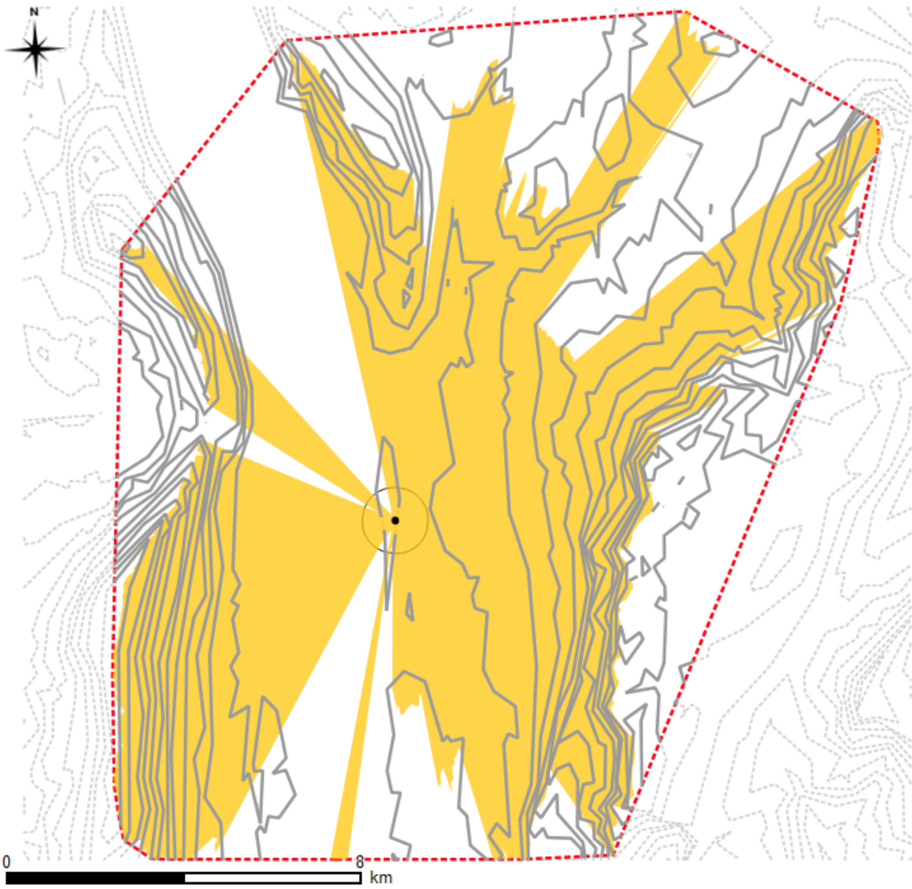

Figure 2: The visual-based clipping technique shows the amount of contour lines, and therefore of terrain, that will not be taken into account in the simulation phase.

### Post-processing

The three terrain models developed (M1, M2, and M3) have been used in the solar simulation and the obtained outcomes compared. Two indicators have been considered in order to test the reliability of our simplification method: the beam (direct) solar irradiation values (Wh/m²) and the daylight duration (min.). Both indicators consider a standard clear sky model and do not take into account sky or model reflections. We decided to conduct the simulation on December, 21$^{st}$ as the day with the lowest sun angles of the year, thus lowest amount of irradiation and daylight.

The measure of irradiation per unit area, depends obviously on the Terrain model itself. More precisely, it depends on its own direction towards the various sun positions, insofar as irradiation understood as the sum of instantaneous density of solar radiation incident on the surface over the given time period is the scalar product of the normal to the face by the sunlight direction).

## III USE CASE

The region of interest, of about 386.5 km² (a 20 km-width square), is located in the French Alps, on the shores of the wide *Lac du Bourget*. In its south part, it embeds a 8 km wide valley oriented north-south which spreads between two mountain ranges (*Le Mont du Chat* and *Les Bauges*) peaking at around 1.5 km over the sea level. In the northern part, on the contrary, the valley broadens and the surrounding ridges sink down (see Fig. 3).

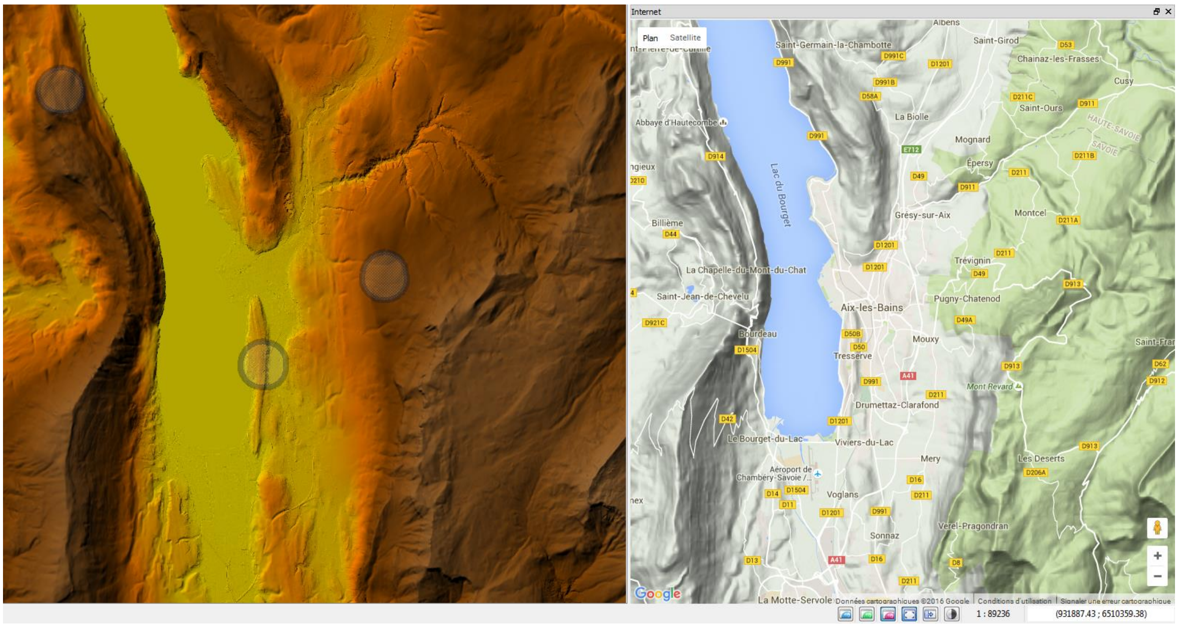

Figure 3: The region of interest with the 3 studied sites (*Ontex* on the NW side, *Pugny-Chatenod* on the East side, and *Tresserve* close to the *Lac du Bourget*).

This region covers a specific inter-communality (the *Communauté d'Agglomération du Lac du Bourget: Grand Lac*) consisting of 17 municipalities. Planning regulations mostly tend to concentrate urban development around the administrative center of municipalities. This aims to allow planning optimization, spaces preservation for natural and agricultural purposes. On this constrained territory, land pressure requires a global project which can be embodied by many strategic locations. We propose to evaluate the sun exposure on those strategic parcels, in the existing fabric or on its boundaries.

In order to select relevant parcels, we assessed the expected impact of terrain on municipalities' center by evaluating the highest aspect ratio (H/W) to the closest relevant ridges (see Table 1).

| **Municipality** | **Aspect ratio** | **Municipality** | **Aspect ratio** |
|---|---|---|---|
| Tresserve | 0.865 | Bourdeau | 0.274 |
| Grésy-sur-Aix | 0.579 | Viviers-du-Lac | 0.252 |
| Méry | 0.445 | Aix-les-Bains | 0.228 |
| Drumettaz-Clarafond | 0.433 | Voglans | 0.220 |
| Le Montcel | 0.430 | Saint-Offenge | 0.208 |
| Mouxy | 0.316 | Brison-Saint-Innocent | 0.184 |
| Pugny-Chatenod | 0.305 | Ontex | 0.147 |
| Trévignin | 0.295 | La Chapelle-du-Mont-du-Chat | 0.088 |
| Le Bourget-du-Lac | 0.284 | | |

Table 1. Characterization of the impact of closest ridges for each municipality center.

Instead of *La Chapelle-du-Mont-du-Chat*, whose administrative center is constrained by the topography, we chose parcels in *Ontex*, on the slope of *Le Mont du Chat* (see Table 2, Fig. 4). We also chose locations on *Tresserve*'s hill and in hillside *Pugny-Chatenod*. Those different locations all embody development opportunities inside the existing urban fabric.

| | ***Ontex* site** | **Pugny-Chatenod site** | **Tresserve site** |
|---|---|---|---|
| **Reference TIN** | M11 | M12 | M13 |
| **Mixed TIN** | M21 | M22 | M23 |
| **Local TIN** | M31 | M32 | M33 |

Table 2. Various nomenclatures (models names) in use.

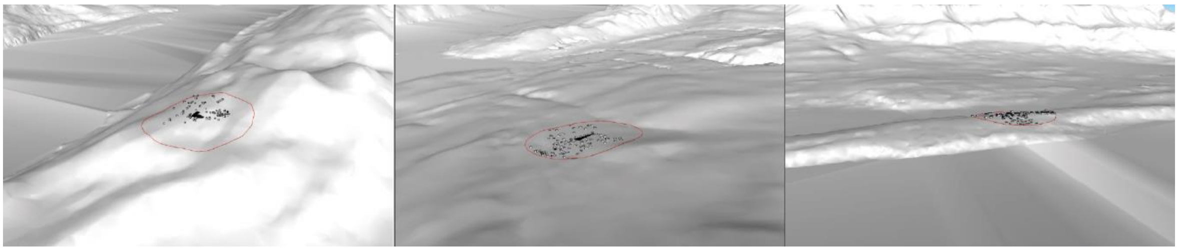

Figure 4: Zoom in the three sites (from left to right: *Ontex*, *Pugny-Chatenod*, and *Tresserve*). The close horizon limits are represented by red circles.

## IV DISCUSSION

Predictably, values obtained from M1 are the lowest and indices' values provided by M3 are the greatest (see Fig. 5). Indeed, a fine modeling of the mountainous Terrain model add new masks to the mock-up and therefore decreases the solar potential of the Terrain patches.

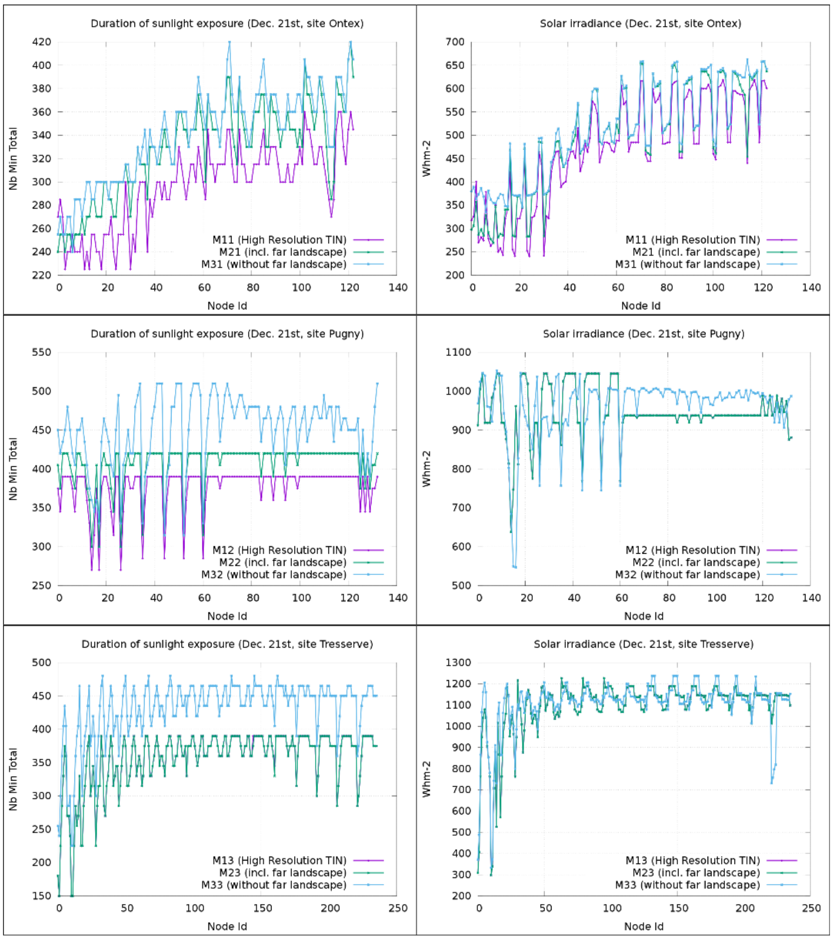


Figure 5: Comparison of the two indicators (duration of sunlight exposure and irradiance, Dec. 21$^{st}$) for the three sites.

The respective average elevations of the three sites vary from 310 m (*Tresserve*), to 604 m (*Pugny-Chatenod*), and 711 m (*Ontex*). The corresponding standard deviation in each site is included between 2 and 3.8 m (with a maximum value in the site of *Tresserve*). Height range between lowest and highest points within a 300 m buffer varies along the three sites. This range is 115 m (from 645 m to 760 m) high at *Ontex*, 125 m (from 555 m to 680 m) at *Pugny-Chatenod* and 75 m (from 250 m to 325 m) at *Tresserve*. On that last site, the closest obstacles do not alter direct irradiance, since they are located in a northerly area. The *Pugny-Chatenod* site is located on a West-East slope, which alters early morning exposure (lower energy input). Eventually, the parcels chosen in *Ontex* are affected by southerly masks (see Fig. 6), that reduce mid-day exposure (higher energy input).

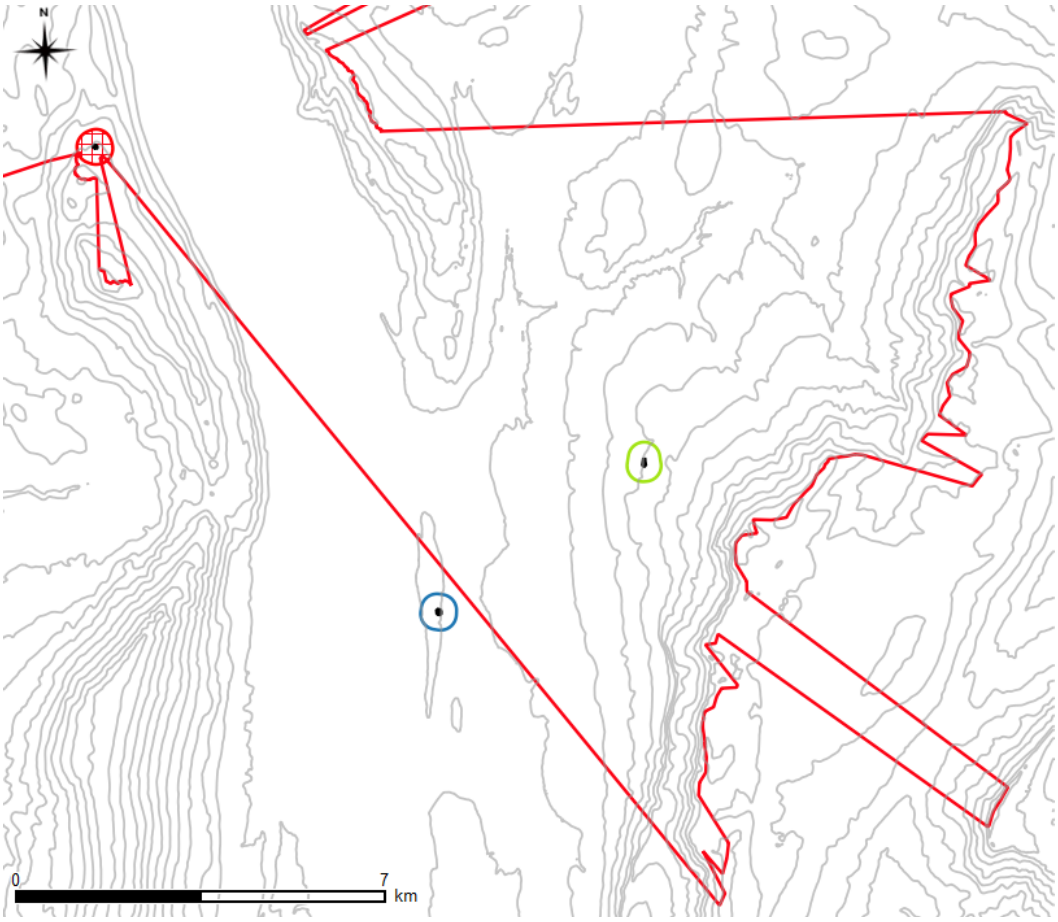

Figure 6: The southern edges of the "cumulative viewshed" of the *Ontex* site (NW) are close from measurement locations (from 180 m to 670 m with a peak of about 1150 m high located just south at about 2.5 km).

As one can notice, for the site located on the top of a small hill close to the lake (*Tresserve*), the coarse-grained model M2 provides simulations results that perfectly match those obtained using the reference Terrain model M1. When the Terrain model gets hillier in the immediate surroundings, simulation outcomes are not as clear-cut. Thus, in the specific case of *Pugny-Chatenod*, where the site is located on a west-facing slope, the coarse-grained model M2 is accurate enough for the irradiation indicator (because it impacts mainly the early morning exposure with lower energy input). However, the mixed TIN M2 is obviously not precise enough to assess the precise daylight duration (there is indeed an average difference of about 30 minutes with the reference values). At last, in the particular case of *Ontex* site, where the Terrain model is particularly hilly nearby the measurement locations, the mixed TIN M2 is undoubtedly inaccurate.

## V CONCLUSION

In our explorative analysis we prove the potentialities and limits of a vector-based approach for analyzing large and complex terrains. Further investigation will be also conducted in order to improve the usability of the SketchUp extension developed in this research. Thus, every territory covered by a DEM could be analyzed, by dynamically changing the terrain site.

Many parameters can also affect the modelling of a site. Closeness has to be defined according to the site location. We proposed a 300 m buffer but this parameter could be subject of a sensibility analysis. This analysis suggests that there should be an optimal obstacle region radius for sunlight access assessment, depending on each site. Generally speaking, adaptive modelling should be the aim of all site analysis. The accuracy of the skyline silhouette also alters the solar exposure. It relies on the distance between contour lines. A sensibility analysis should also be led on that parameter to determine how the level of detail of the terrain model affects the calculation of solar radiation indicators.

We proposed that the solar exposure could be defined efficiently thanks to a site-centric modelling. The relevant obstacle region around the observing point depends on the urban fabric. This approach could be extended to other case studies, for a wide set of density range: from the open field to the high medieval urban fabric.

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